Syntroleum

September 12, 2001

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Ms. Linda Bluestein
Program Manager
Alternative Fuel Transportation Program
U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, DC 20585

Dear Ms. Bluestein,

In response to your letter of August 23, 2001, Syntroleum is pleased to provide the following responses to your questions regarding our EPAct petition for the DOE completeness and technical review of the Syntroleum petition. For sake of clarity, we have restated your questions ahead of our responses.

Petition Reviewers' Questions

1. ***Distinguishing between S-2 and FT Naphtha.*** The Syntroleum design produces naphtha and middle distillates (S-2, as Syntroleum calls it). Syntroleum states that S-2 can be used either as a CIDI fuel or a fuel cell fuel. But we thought that the naphtha from FT plants could be used as a fuel cell fuel, not the FT diesel. Please clarify.

   Syntroleum Response: Both FT Naphtha (FC-2) and S-2 diesel can be used for fuel cell fuels. As saturated hydrocarbons (> 99% paraffin) both fuels offer significant advantages over other liquid fuels such as methanol and gasoline since they deliver more hydrogen per unit volume with no associated environmental issues such as toxicity and bio-degradability. Table 1 below presents a summary of tests performed by IdaTech[1] on several Syntroleum fuels along with a test of commercial methanol. Syntroleum S-1 is a light product taken directly from the FT reactor and Syntroleum S-5 is synthetic fuel formulated to meet military jet fuel (JP-5) specifications. It should be noted that different catalyst formulations were used to test the FT fuels with dramatically different results. Based on tests using the same catalyst (G91), FC-2 had a slightly higher conversion into hydrogen than

[1] D. Edlund, W. Pledger, B. Trunbull and B. Russell, An *Analysis of Hydrogen Production from FT Liquids for use in Fuel-Cell System*, SAE Paper 2001-01-1918, International Spring Fuels and Lubricant meeting, May 2001, Orlando, FL, USA.

Syntroleum Corporation • 1350 South Boulder • Suite 1100 • Tulsa, Oklahoma 74119-3295 USA
(918) 592-7900 • FAX (918) 592-7979

did S-2. Both had significantly higher hydrogen yields (25 to 100 % increases) compared to methanol.

Table 1. Summary of Hydrogen Yields

Fuel Tested	Catalyst	H2 Production, Std. L/L of fuel
Syntroleum FC-2	G91	1500 – 1900
Syntroleum S-2	G91	1500 – 1800
Syntroleum FC-2	FCR-9	2600 – 3200
Syntroleum S-1	FCR-9	2400 – 3200
Syntroleum S-5	FCR-9	2300 – 3300
Methanol	G66B	1200 – 1500

The main issue here is the duality of FT fuels. It is important to make a distinction between fuels that are blended for combustion and fuels that are suitable for use as a feedstock in a fuel cell. The relative purity of FT liquid fuels (whatever the boiling point may be) makes them more amenable for hydrogen production than petroleum-derived hydrocarbon fuels. Their lack of sulfur compounds and under-saturated hydrocarbons are expected to lower maintenance costs, simpler system design and reduce cost of operation for fuel cell reformers. More significantly, internal combustion engines can be run on synthetic FT liquid fuels <u>without modifications</u>, thereby providing a ready bridge to the adoption of fuel cell engines in vehicles.

2. ***Co-Generated Steam.***

Question 1: In its 02/19/2001 response to DOE, Syntroleum states that its FT design produces low-pressure (LP) steam with 140 psi and high-pressure (HP) steam with 700 psi. We'd like to know the split between the two types of steam.

Syntroleum Response: While each FT plant is site specific, in this case the split between LP and HP steam was about 50/50.

Question 2: Syntroleum indicates that it will upgrade LP steam to HP steam with tail gas or other process fuels. Please clarify if this is the design intention. In this case, we'd like to know if energy used for the upgrade is taken into account in energy efficiency calculations.

Syntroleum Response: In reference to the question above, some clarification is in order. Syntroleum did not indicate that we would be producing HP steam from LP, but rather we could generate additional amounts of HP steam by recovering heat from turbine exhaust via an HRSG. The original statement was:

> *"In addition to the recovery of process heat for steam generation and electrical generation, there is significant recoverable heat in the process "tail gas" in the form of plant turbine exhaust. (A low Btu gas fired turbine is an integral part of typical Syntroleum Process plant designs.) For plants with sufficient demand for steam, a heat recovery steam generator ("HRSG") may be used to derive additional energy from the turbine exhaust to generate additional HP steam. This HP steam can generate electricity and additional amounts of MP steam in a back-pressure turbine."*

Question 3: In Tables 3 and 4, Syntroleum presents data for two different FTD plant designs – one with steam export only, and the other with steam and electricity export. Oddly, the amount of steam exported with the option of steam and electricity export is greater than the amount of steam exported with the option of steam export only. This may be due to different qualities of steam from the two designs. If so, please specify the pressure and temperature of the steam from each design.

Syntroleum Response: Both the ATR and FT reactions are exothermic. In order to control the process and remove this heat, steam is raised from both of these reactions. Saturated HP steam (700 psia/503 F) is generated in the ATR quench exchanger and is used to provide motive power for various pieces of rotating equipment. Based on the individual plant design and the power train configurations, variable amounts of HP steam are available for export depending on plant design. Saturated LP steam (140 psia/353 F) steam is generated in the FTR steam drums. This steam is used for various pre-heat duties, product upgrading column feeds and general plant use (vessel and pipe steam tracing). The balance is available for export. For the "steam and electricity export" case, HP steam is generated in the HRSG (as described above) and then used to generate electricity in a back pressure turbine with a backpressure of 140 psia, thus creating additional quantities of exportable LP steam and exportable power. Attachment C shows the process configurations used in the three cases presented in our petition revisions dated 2/19/01.

Question 4: The pressure of HP steam (700 psi) is still far below the pressure of the steam from steam boilers in electric power plants for electricity generation (above 2000 psi and above 1000 F of temperature). Thus, it is conceivable that the efficiency of electricity generation with the FTD HP steam will be still below the efficiency of conventional electric power plants. What is the electricity generation efficiency with the 700-psi steam that is assumed by the Syntroleum in its analysis?

Syntroleum Response: Based on vendor specifications, the adiabatic efficiency of the steam turbines used to generate electricity was assumed to be 75 %. The mechanical shaft efficiency was assumed to be 98.5 %.

3. ***Water Export.*** Syntroleum states that roughly one barrel of water is produced for each barrel of FT product. How much of the water potentially could be exported as a commercial product, besides its use as boiler feed water in FTD plants?

   Syntroleum Response: The amount of exportable water is a site-specific issue as it pertains to plant cooling requirements. In arid areas with limited or no access to cooling water (fresh river water or sea water), process heat may be removed by air fan coolers or cooling towers. Produced water can be used for cooling tower make-up. In areas with access to river or seawater, the plant cooling may also be accomplished through circulation of water these sources. This increases the availability of process water for export up to 90 % of the total process water produced.

4. ***Three Cases Analyzed.*** Among the three cases of FTD plant designs (standalone, steam export, and steam and electricity export), economics may prevent the third case (design with both steam and electricity export), especially when one notices the infrastructure requirement for and costs of exporting both steam and electricity. One might expect that FT plants may be designed to export only one of the two products, not both, in most cases.

   Syntroleum Response: The design of each FT plant and its integration with potential steam and power consumers is site specific. While your comment might be correct in some instances, we currently have projects under consideration that do encompass the export of both steam and power without any significant infrastructure requirements. By way of example, we are currently developing a project where the FT plant would be located within the battery limits of an existing power plant using natural gas turbines to produce and delivery power to the local grid. This particular project would have the FT plant deliver steam for power generation during peak periods as well as surplus power from the FT plant. Within the same fenced area there is a desalination plant that would also be a consumer of the exportable LP steam.

5. ***P.47, Hydrogen and Process Fuel Requirements to Produce 15-ppm Diesel and Light Cycle Oil (LCO).*** Based on the input and output data in the table on this page, we calculate a refinery energy efficiency of 95% for 15-ppm diesel and 88% for LCO. The 15-ppm diesel efficiency seems too high. There might be some other

refinery energy uses missing from this table. Please clarify this. In any event, please provide overall refinery energy efficiencies for 15-ppm diesel and LCO.

Syntroleum Response: Syntroleum used GREET model 1.5a as the basis of our full fuel-cycle energy and emission analysis. GREET assumes an overall refinery energy efficiency of 87% to produce a reformulated diesel (RFD) having a sulfur content of 50 ppm. In order to determine the overall energy use for 15 ppm RFD, Syntroleum evaluated (external to the GREET model) the most likely amount of process energy and hydrogen required (using current technology) to hydro-treat RFD to lower its sulfur content from 50 ppm to 15 ppm. We also performed a similar evaluation to determine the energy and hydrogen required to hydrotreat the same volume of a typical diesel blend component, FCC light cycle oil (LCO), to 15 ppm. Based on these evaluations (detailed in Attachment 3 of the original petition, pages 47-49) the overall refinery efficiencies required to produce 15 ppm diesel and LCO are 85.7 % and 82.8 % respectively.

6. ***Sub-Quality Gas.*** On Page 11 of the petition, Syntroleum states the potential use of "sub-quality gas" for FTD production. What are the energy efficiency and emission consequences of using sub-quality gas, relative to pipeline-quality gas?

   Syntroleum Response: The Syntroleum process can produce FT fuels from gas feedstocks having concentrations of nitrogen and/or carbon dioxide up to 30 % with a demonstrated (commercial scale) maximum limit of 12 % on the carbon dioxide. Since both of these gases are inert, the mass flow heat duties for the plant would increase proportional to their concentration. In the case of the nitrogen, this would be a net increase in duty. In the case of carbon dioxide, some of this heat duty is offset by reforming carbon dioxide into carbon monoxide in the ATR, which then converted in liquid fuel in the FT reactor. If this feed gas were to be processed for pipeline deliver rather than to a GTL plant, the concentrations of nitrogen and carbon dioxide would have to be reduced to maximum limits of 4 % and 2 % by volume respectively. Typically, a cryogenic nitrogen rejection unit (NRU) is used to remove nitrogen. Carbon dioxide is typically removed in an amine absorption unit (AAU). Removal of either or both gases requires energy proportional to there concentration. Syntroleum has made no attempt to quantify the net energy gains or losses of gas processing for pipeline delivery versus use of the gas in a Syntroleum FT plant.

7. ***Please Provide the following***:

   Density of the fuel (in grams/gallon)

   Carbon content by weight

   Sulfur content by weight

   Heat content (Btu/gallon, lower and higher heating values.)

   Syntroleum Response: Please refer to Table 2 below.

   Table 2. Selected Fuel Properties

S-2 Property	Test Method	Value
Density, grams/gallon	ASTM D-4052	2,915
Carbon content, wt %	ASTM D-5291	84.92
Sulfur content, wt %	ASTM D-2622	<0.001
Higher heating value, btu/gallon	ASTM D-240	130,315
Lower heating value, btu/gallon	ASTM D-240	121,538

8. What are the aromatic, olefinic and paraffinic contents of S-2 by ASTM D5291, or equivalent method?

   Syntroleum Response: ASTM D-5291 is a determination of carbon, hydrogen and nitrogen in petroleum products and lubricants and therefore is not an appropriate test for the measurement of aromatic, olefinic and/or paraffinic content of S-2. In testing our fuel for purposes of the petition the SwRI tested S-2 for hydrocarbon type by ASTM D1319, Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption. The results are shown in Table 3 below.

   Table 3. S-2 Hydrocarbon Type by FIA, volume %

Aromatics	N/D*
Olefins	N/D*
Saturates	>99 %

* Below the detection level of the test procedure

9. What are the physical and chemical property specifications for S-2

   Syntroleum Response: The physical and chemical properties of S-2 were submitted in the original petition on page 8 as Table 1. Comparison of Physical and Chemical Properties. For sake of completeness this table is presented again as Attachment B to this letter.

10. Are results available for the biodegradability or S-2 per ASTM E1720-95 or equivalent method (OECD method 209 Pseudomonas putida Growth Inhibition Test)?

    Syntroleum Response: The only biodegradability data Syntroleum has is based on partial results from an air-blown aerobic test, ASTM D5864, Determining Aerobic Aquatic Biodegradation of Lubricants or Their Components. In this test, the biodegradation of a sample is measured by collecting and measuring the CO_2 produced when the sample is exposed to microorganisms under controlled aerobic aquatic conditions. This test is designed to measure CO_2 production from the sample over a 28 day period. During this analysis of S-2, after about two weeks of very active aerobic activity (as determined by the CO_2 evolution) our sample evaporated and the aerobic activity went to zero. Syntroleum is evaluating the appropriateness of this test method for highly biodegradable fuels such as S-2. It should be noted saturated FT lubricants in the boiling range of S-2 are the preferred base oils for drilling mud formulations used in offshore drilling of their known benign environmental qualities.

11. The petition gives a batch analysis of S-2 in with the emissions test results. Is this analysis typical of the S-2 fuel covered in the petition? If not, which fuel properties may vary? How much can the fuel properties vary from the results given in the batch analysis in the petition?

    Syntroleum Response: We assume you are referring to Table 4. Diesel Fuel Specifications on page 17 of the original petition. The information presented for S-2 is typical data and should not vary with respect to the sulfur and aromatic content, both being at non-detectable levels. Since S-2 is produced by distillation of a spectrum of hydrocracked and isomerized paraffins, final characteristics of S-2 such as density and cetane number will vary slightly during normal production cycles to meet market requirements. We estimate that the density could vary by +/- 2 API degrees and the cetane number could vary by +/- 3 cetane numbers.

12. Provide the oxygen content, in percent, of the S-2 fuel.

Syntroleum Response: Syntroleum tested samples of S-2 through an external lab using ASTM test method D5599, which measures oxygenates down to 0.01 wt % (100 ppm) in gasoline fractions. Oxygenates detected by this test are principally alcohols. Using this test on numerous samples of S-2, the oxygen content measured at the 100 ppm lower detection limit. D5599 however, is designed for gasoline and only detects alcohols to pentanol.

Syntroleum has been using an in house developed, wet chemistry method for determining all alcohols down to 400 ppm and the method is being expanded to measure alcohols down to 100 ppm. Syntroleum is also using an in house wet chemistry method to determine carbonyls (sum of aldehydes, ketones, carboxylic acids etc.) down to 1 ppm. Alcohols and carbonyls, but mainly alcohols, are the primary source of oxygen. Syntroleum's fuels have tested well below 400 ppm alcohols, expressed as decanol, and below 1 ppm carbonyls expressed as the carbonyl group. By these test methods we estimate the total oxygen content of S-2 to be between 10 to 40 ppm.

Please see Attachment A regarding energy inputs, co-product outputs, emission outputs and plant efficiencies for the various Syntroleum plant process configuration cases presented in the petition (including our revisions dated 2/19/01).

Syntroleum appreciates the opportunity to respond to the DOE questions. We have tried to provide data sufficient for the DOE to complete the review process and to determine Syntroleum S-2 to be an alternative fuel under the provisions of EPAct.

We look forward to participating in your planned workshop. If there are any additional questions or the need for clarification regarding the information presented herein, please contact me.

Sincerely,

R. Steven Woodward
Manager Fuel Sales

cc: Larry Weick - Syntroleum

Attachment A – Completed Forms

Table 1. Co-Product Outputs per Million Btu of Fischer-Tropsch Fuel

Output	**Relative Btu Content – Syntroleum Cases**			
	Flared Gas	Stand Alone	Steam	Steam & Power
Fischer-Tropsch Fuel	1 million Btu			
Co-Product #1: Steam	-	-	347,000 Btu	542,000 Btu
Co-Product #2: Electricity	-	-	-	9.3 KWh

Table 2. Energy Inputs Million Btu of Fischer-Tropsch Fuel

Energy Inputs	**Relative Btus – Syntroleum Cases**			
	Flared Gas	Stand Alone	Steam	Steam & Power
Natural Gas	0*	2,040,816 Btu	2,040,816 Btu	2,040,816 Btu

* No energy input is shown since the natural gas feedstock is flared gas that would otherwise have been wasted.

Table 3. Emission Outputs for Fischer-Tropsch Fuel and Co-Products of Table 1 with Corresponding Energy Inputs of Table 2.

	Criteria Emissions, grams			**Greenhouse Gases, grams**		
Syntroleum Case	VOC	CO	NOx	CO2	Methane	N2O
Flared Gas	(2.11)	(12.94)	(61.10)	(64,993)	(82.10)	(1.90)
Stand Alone	2.27	32.63	24.59	37,147	3.76	0.03
Steam	0.70	9.34	3.06	9,049	(41.66)	(0.48)
Steam & Power	(0.34)	(4.74)	(12.19)	(10,218)	(67.69)	(0.83)

Table 4. Key Plant Information

Syntroleum Case	Flared Gas	Stand Alone	Steam	Steam & Power
Energy Efficiency (excluding co-generated steam or electricity in Table 1) in percent	57 %	49 %	49 %	49 %
Carbon Efficiency (carbon in products divided by carbon in natural gas feed) in percent	65 %	72 %	72 %	72 %

Attachment B. Comparison of Physical and Chemical Properties

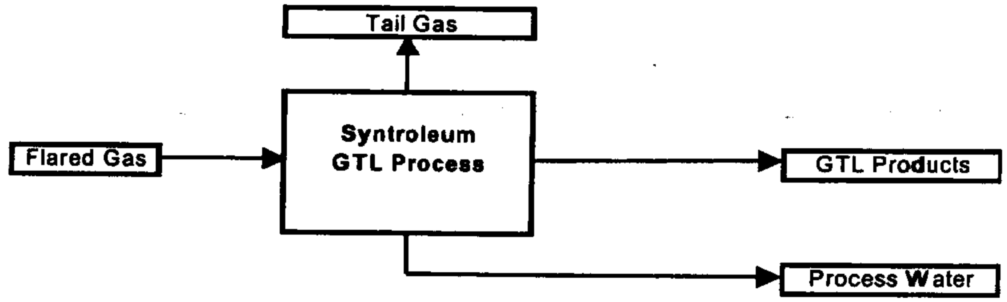
Property	Test Method	Units	Syntroleum S-2	EPA # 2 Diesel
Specific gravity	ASTM D – 1298		0.771	0.846
API	ASTM D – 1298	^{o}(degrees)	52.0	35.9
Reid Vapor Pressure	ASTM D – 323	psi	0.5	N/A
Flash Point	ASTM D – 93	^{o}F	148	157
Cloud Point	ASTM D – 2500	^{o}F	<0	32
Color	ASTM D – 1500	Inspection	<0.5	25
Sulfur	ASTM D – 2622	Wt %	N/D	.05
Viscosity	ASTM D – 445	cSt@104^{o} F	2.1	2.5
Carbon Residue	ASTM D – 524	Wt %	<0.05	.35
Copper Strip	ASTM D – 130	Inspection	1a	1
Aromatics	ASTM D – 1319	Vol %	N/D	30
Olefins	ASTM D – 1319	Vol %	N/D	1
Saturates	ASTM D – 1319	Vol %	>99%	69
Cetane Number	ASTM D – 613		>74	45
Oxidation Stability	ASTM D – 2274	mg/100 ml	0.0	
Distillation – IBP	ASTM D – 86			
Initial Boiling Point		^{o}F	320	363
@ 10 vol % recovered		^{o}F	390	420
@ 50 vol % recovered		^{o}F	493	497
@ 90 vol % recovered		^{o}F	601	590
Final Boiling Point		^{o}F	662	646
Lubricity	ASTM D – 6079	mm	<0.37	N/A
Ash	ASTM D – 482	Wt %	<0.001	0.01

\a\ N/D – Not Detectable
\b\ N/A – Not Applicable

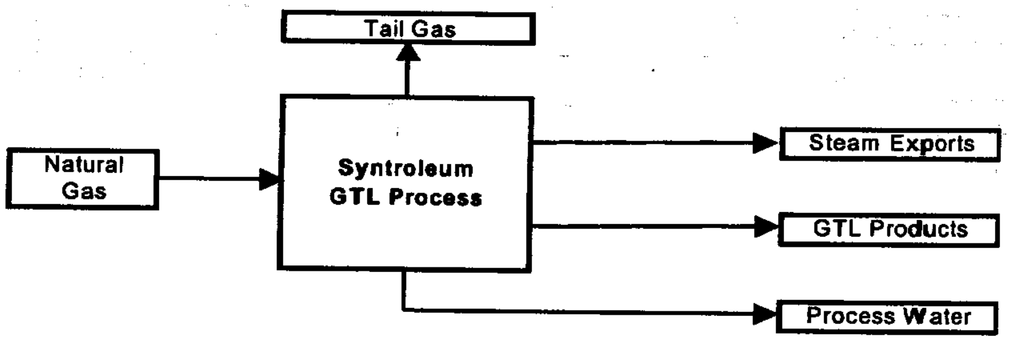
Attachment C.

Syntroleum GTL Plant EPAct Process Configurations

Case 1: Stand Alone GTL Plant



Case 2: GTL Fuel Plant Exporting Steam



Case 3: GTL Fuel Plant Exporting Steam and Electricity